Australian Journal of Earth Sciences
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t716100753

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To cite this Article Salama, R. B. , Farrington, P. , Bartle, G. A. and Watson, G. D.(1993) 'The role of geological structures and relict channels in the development of dryland salinity in the wheatbelt of Western Australia', Australian Journal of Earth Sciences, 40: 1, 45 — 56

To link to this Article: DOI: 10.1080/08120099308728062

URL: http://dx.doi.org/10.1080/08120099308728062

Australian Journal of Earth Sciences (1993) **40**, 45–56

The role of geological structures and relict channels in the development of dryland salinity in the wheatbelt of Western Australia

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Aerial photogeological interpretation techniques have been used to map the geology, delineate the geological structures and identify the relict channels of three representative dryland salinized catchments in the wheatbelt of Western Australia. Much of the variation in groundwater salinity is explained by the distribution of geological structures (dykes, veins and basement highs) in relation to the alluvial systems and relict channels and their effect in modifying groundwater flow. Salinities in the relict channels are generally higher than in other areas of the catchment. Salinity also increases in the direction of groundwater flow along the relict channel. Salinity in groundwaters upstream of geological structures is without exception higher than in other parts of the catchment. The relict channels are found to have an important role in the storage and redistribution of salt in the landscape.

Key words: geological structures, groundwater salinity, relict channels, Western Australia, wheatbelt.

INTRODUCTION

Salinization of soils and streams in dryland agriculture is now recognized as an increasing problem of land degradation in southern Australia (Peck *et al.* 1983). The widespread clearing of perennial native vegetation for the development of agriculture has been reported to be the primary cause of salinity in Western Australia (Peck *et al.* 1983; Peck & Williamson 1987; Schofield *et al.* 1988) and in other states (Cope 1958; Jenkin 1981; Dyson 1983; Williamson 1983; Allison *et al.* 1985; Knight *et al.* 1989).

In Western Australia, considerable progress has been made during recent years in understanding the salinity problems in the Darling Range (Peck & Williamson 1987; Schofield *et al.* 1989), but less is known about the processes causing salinity in the semi-arid wheatbelt region of Western Australia. Soil landscape studies by CSIRO Division of Soils (Bettenay 1962; Bettenay *et al.* 1964; Mulcahy & Bettenay 1972; Mulcahy 1978) associated the incidence of salinization with the unique geomorphology of the wheatbelt. During the past 50 Ma, the landscape has been deeply weathered and eroded to a low relief. Weathering of the granitic and metamorphic basement rocks of the Precambrian shield has resulted in the formation of lateritic podzolic soils with a deep pallid zone of sandy clay with low permeability. As a result of erosion, the wheatbelt now consists of extensive areas of sandy uplands underlain by lateritic mottled and pallid weathered zones dissected by broad valleys of low gradient and subdued drainage. It is implied from studies such as those by Dimmock *et al.* (1974), Johnston and McArthur (1981) and R. George (pers. comm. 1990) that the soils and aquifers store large amounts of soluble salts. Groundwater systems associated with salinization have been studied by Bettenay *et al.* (1964), Williamson and Bettenay (1979) and Nulsen and Henschke (1981). They suggested that these systems occur in semiconfined to confined aquifers in the pallid zone and are characterized by low hydraulic conductivities and low gradients. Once the area has been cleared, salinity usually develops in the valley floor and depressions. This is caused by increased groundwater discharge due to elevated hydraulic heads in the aquifers following increasing recharge in the intake areas of the valley slopes.

Bettenay (1978) and Engel *et al.* (1987) reported that a dolerite dyke can induce a saline seep in the landscape by acting as a linear hydraulic barrier which impedes groundwater flow and forces saline groundwater to the soil surface.

This paper examines the feasibility of using simple aerial photograph interpretation techniques to identify the geological structures and relict channels. The paper also examines the extent to which the presence of geological structures affect the development of salinity at the catchment level in three different areas, and examines the role of relict channels in the development of salinity in the wheatbelt.

BACKGROUND AND METHODS

Three catchments were studied. Their locations, shown in Fig. 1, are:

(i) Cuballing catchment (Falls Farm catchment): the catchment lies 15 km northeast of Narrogin. It covers an area of 1.75 km^2 (Fig. 2) and has an elevation ranging from 340 to 415 m above mean sea-level.

(ii) East Perenjori catchment: the catchment which is located 30 km east of Perenjori has an area of 139 km^2 (Fig. 3). The catchment takes the form of

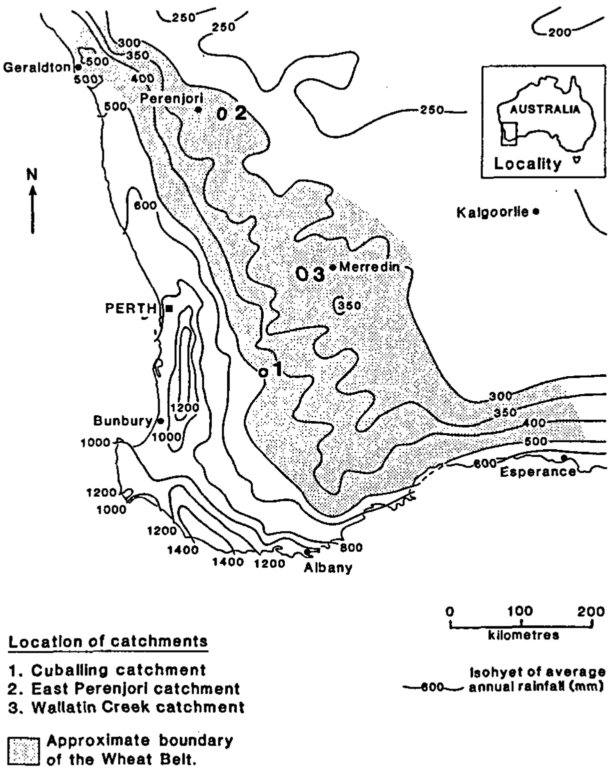

Fig. 1 Location map of the three experimental catchments, and the approximate boundary of the wheatbelt.

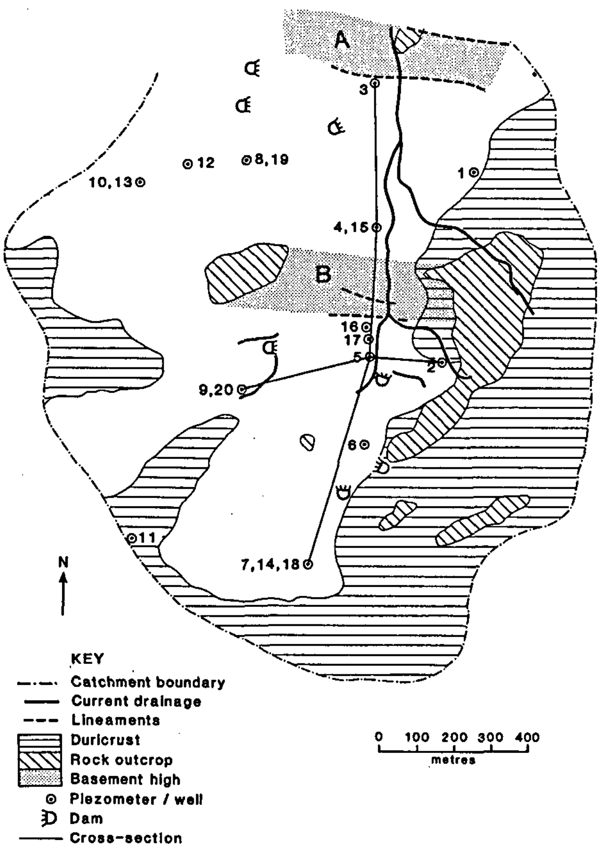

Fig. 2 Cuballing catchment, showing the drainage system, duricrust, rock outcrops, basement highs, lineaments and location of piezometers or wells. The basement highs and associated dykes (A & B) divide the catchment into two compartments. Map prepared from aerial photographs and data incorporated in the Western Australian Department of Agriculture GIS system.

a narrow elongated basin (23 km long and 5–8 km wide). Elevations range from 270 to 366 m above mean sea-level.

(iii) Wallatin Creek catchment: the catchment is located northwest of the Doodlakine townsite and has a total area of about 250 km^2 (Fig. 4). The catchment is relatively long and narrow (30 km long and 8–12 km wide). Elevation at the catchment divide is about 390 m and falls 130 m to the confluence of the major drainage line, the Yilgarn River.

The climate in all catchments is Mediterranean with hot dry summers and mild wet winters. The average annual rainfall ranges from 462 mm at Cuballing to 350 mm at Wallatin Creek and 310 mm at East Perenjori.

In each catchment the Western Australian Department of Agriculture has conducted the initial investigations by carrying out soil and geophysical surveys, and installing a network of piezometers and observation wells.

Aerial photogeological interpretation was carried out by stereoscopic examination of aerial photographs of the three catchments (Table 1). Lineaments, dykes, basement highs and veins were readily mapped because they contrast with the surrounding landscape due to their greater resistance to weathering or differences in soil colour. The relict channels were identified by their paler tone caused by aeolian or alluvial sediments deposited in the channels. Granitic outcrops were identified by their weathering pattern of massive boulders. Lateritic remnants and escarpments were readily identified by their breakaway pattern. Thin lateritic duricrust on top of granite was not readily identifiable from the basement rocks in aerial photographs. The prepared maps were compared with 1 : 250 000 Geological Series maps and confirmed by field visits to each catchment. Aerial imagery scanning was also used for the Cuballing catchment.

Samples from drill cuttings and cores from further exploratory boreholes (drilled by CSIRO as part of a project funded by the National Soil Conservation Program), together with the geological logs from previously drilled wells, were also used to study and identify the different geological formations, depth of weathering and the nature of regolith in each catchment. Core samples were examined in detail. Samples were washed and grains were studied under the microscope for degree of roundness. Mineral assemblages were also examined. Two samples from sedimentary sections were dated using palynological techniques. Groundwater samples were collected twice per year from representative wells or piezometers in each catchment. Samples were analysed in CSIRO laboratories using standard methods for major cations and anions.

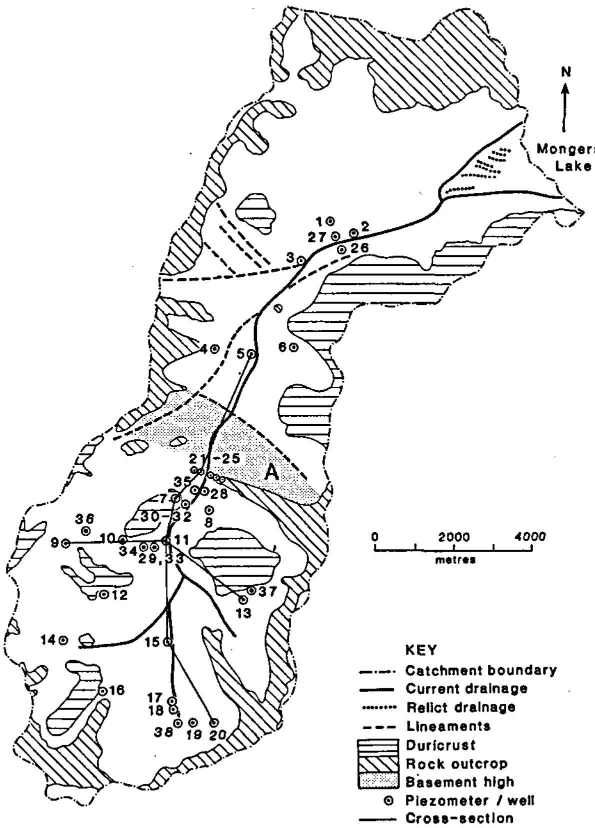

Fig. 3 East Perenjori catchment, showing the drainage system, duricrust, rock outcrops, lineaments and location of piezometers or wells. The basement high (A) divides the catchment into two compartments. Map prepared from aerial photographs and data incorporated in the Western Australian Department of Agriculture GIS system.

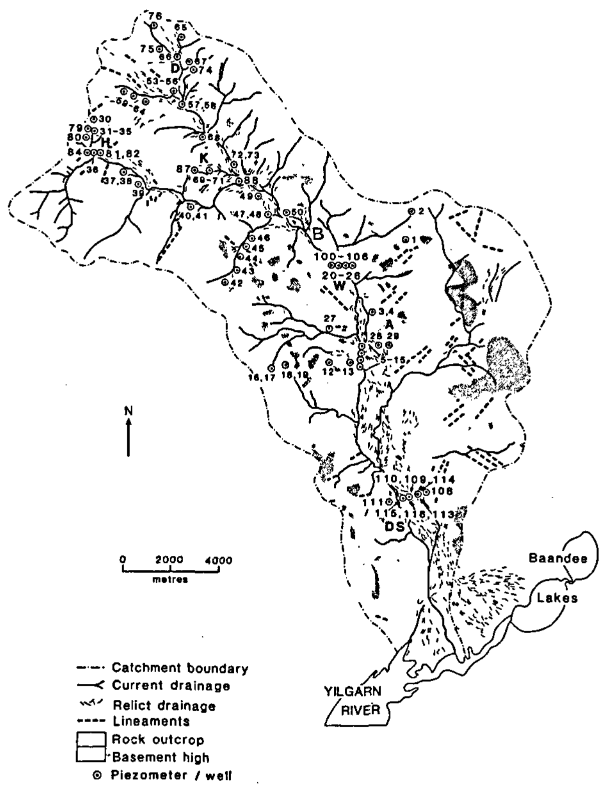

Fig. 4 Wallatin Creek catchment, showing drainage system, relict channels, duricrust and rock outcrops, and lineaments. Basement highs and associated lineaments (A & B) separate the catchment into several compartments (D: Durokoppin reserve, K: Kodj Kodjin reserve, H: Harvey section, W: Wallatin section, DS: Doodlakine section). Map prepared from aerial photographs and data incorporated in the Western Australian Department of Agriculture GIS system.

Table 1 Aerial photographs used in the study.

Title	Date	Film no.	Run	Photo no.	Scale
Wallatin Creek Catchment					
Kellerberrin	30.10.64	CAF 4017	4	291–293	1:86 000
		CAF 4029	5	3546–3548	1:86 000
Kellerberrin Soil Conservation	12.7.86	WA 2438C	1–7	5001–5086	1:20 000
Cuballing Catchment					
Corrigin	2.4.62	WA 771	15	5342–5343	1:40 000
Cuballing	17.3.88	WA 2586C	1	5037–5042	1:10 000
East Perenjori Catchment					
Perenjori	17.11.59	WA 588	10	5151–5162	1:31 680
			11	5095–5101	1:31 680
			12	5017–5023	1:31 680
			13	5132–5140	1:31 680
Perenjori	16.4.88	WA 2647C	1	5067–5073	1:50 000

Aerial photographs provided by the Department of Land Administration, Perth, Western Australia.

GEOLOGY

The three catchments are within the Western Gneiss Terrane and the Southern Cross Province of the Yilgarn Craton (Trendall 1990). The Western Gneiss Terrane is formed mainly of repeatedly deformed and metamorphosed banded gneiss, including quartz-rich metasedimentary rocks and banded iron formation, with scarce metavolcanic rocks and higher metamorphic grade suites (amphibolite or granulite), and with widespread intrusions of granite either in the form of sheets (in the north) or plutons (in the south). The Southern Cross Province is formed mainly of two sequences of greenstone separated by an unconformity, gneiss and granitoids (Griffin 1990). The lower sequence contains a quartzite unit at the base overlain by mafic and ultramafic volcanic rocks. The upper sequence occurs only in the centre of the province and consists of clastic sedimentary and felsic volcanic rocks.

The Yilgarn Craton is cut by two major groups of basic dykes; relatively thick east–west dykes that are widely spaced and distributed throughout the Yilgarn Craton; and dense swarms of relatively thin dykes that are concentrated around the craton margins (Myers 1990). The widespread east–west dykes are generally 10–50 m thick and can be traced for tens to hundreds of kilometres. Most of these dykes are massive olivine dolerite or gabbro and are subvertical. The relatively thin northwest dykes which are mainly tholeiitic dolerite, are subvertical and range from 2 to 20 m thick. Some of these dykes have normal magnetic polarity, while others have reverse polarity. The greenstone and gneiss belts, as well as the major faults, trend in a north-northwest direction.

The craton is covered by transported or residual, unconsolidated to indurated regolith. It includes alluvial, aeolian and colluvial sediments and siliceous, ferruginous and calcareous duricrusts. Unconsolidated to semiconsolidated, dominantly sandy alluvium occurs along most major drainages. Alluvial deposits grade laterally into colluvial, diluvial and residual deposits. All have undergone varying amounts of aeolian reworking in most areas (Hocking & Cockbain 1990).

Cuballing catchment

The catchment is bounded to the east, southwest and west by scattered lateritic duricrust and to the southeast by granitic rocks (Fig. 2). The valley sides are formed mainly of granitic outcrops on the eastern side, and indurated lateritic duricrust on the western side with some scattered outcrops of granite in the valley. Aerial photographs show the presence of east–west lineaments in the northern and central parts of the catchment. These lineaments have also been readily identified from image processing and enhancement of Landsat thematic mapper data. A geophysical study conducted by Engel *et al.* (1987) has identified these structures as dolerite dykes and this is confirmed by recent detailed field work. A northward lineament, along which the stream is flowing, occurs at the contact of granite on the eastern bank, and sediments and weathered profile on the western bank, possibly along a fault line. The younger east–west dykes cut across the lineament.

East Perenjori catchment

The catchment (Fig. 3) is 90% covered by superficial sediment and weathered material, which includes lateritic duricrust, alluvium and colluvium (Henschke 1989). Archaean granitoid rocks crop out along the sides of the catchment, with several outcrops occurring in the northern section. The outcrops in the central part of the catchment form a constriction across the valley. The granitoid is mainly adamellite–granodiorite, and medium-grained adamellite with less than 10% feldspar (Baxter & Lipple 1985). The aerial photographs show the presence of a major lineament extending northeast just north of the area constricted by basement rock. Several other lineaments also extend along west and northwest directions (Fig. 3). The southern part of the catchment is characterized by the presence of a series of breakaways underlain by highly weathered granitoid rock.

Wallatin Creek catchment

The catchment is bounded by pockets of lateritic duricrust and basement outcrops (Fig. 4). The basement rocks cropping out in the catchment consist of seriate porphyritic adamellite which form the main part of Kellerberrin Batholith (Chin 1986). Several outcrops extend across the main drainage lines. Numerous lineaments trending northeast and northwest, with some east–west ones, cut across the drainage lines. Most of these lineaments have been identified as dolerite dykes associated with basement highs.

REGOLITH DESCRIPTION

Cuballing catchment

Drilling logs for wells in the Cuballing catchment indicate that the regolith is formed of alluvium, colluvium and weathered material, which in certain areas is more than 30 m thick (Henschke 1982). The alluvial sequence occupies a very narrow band parallel to the stream and thins towards the eastern flanks of the catchment where highly weathered bedrock material consisting of angular quartz and weathered biotite and feldspars is encountered. The thickness of the alluvial material in the channel varies from a few metres in the upstream part of the catchment to 20 m in the central part upstream of the southern basement high (Fig. 5a,b). It is formed of sand and gravel, sandy clay, sandy clay loam and clay. The sand is mainly subrounded to subangular with few well rounded particles. Colluvium is formed mainly of grey to brown loamy sand. In some places it consists of ironstone gravel and boulders in a matrix of brown loamy sand and clay. Two types of colluvium have been identified: colluvium (A), present on the eastern flank of the catchment, is

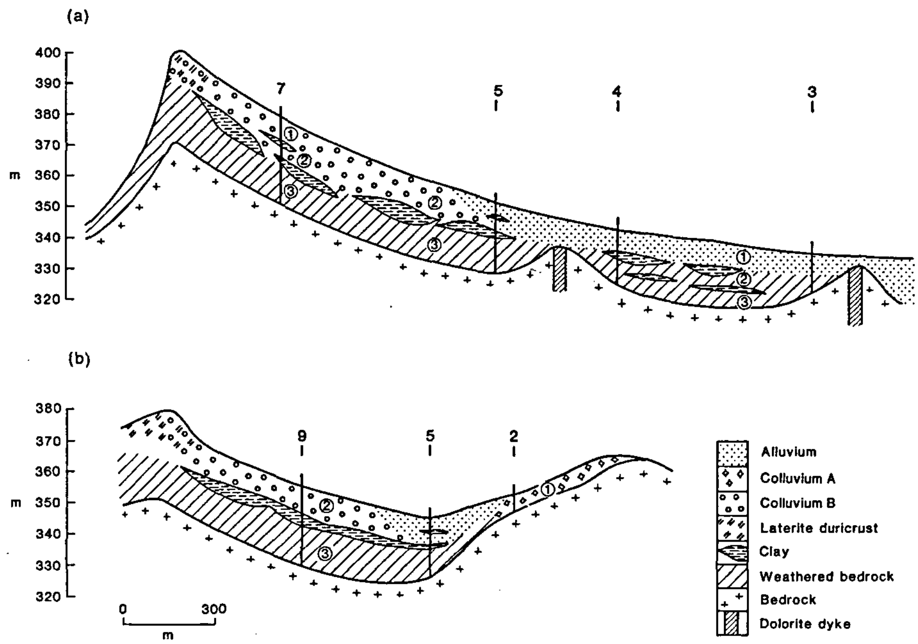

Fig. 5 (a) Cross-section of the Cuballing catchment showing the relationship between the different lithological units and the location of the two basement highs and associated dykes. The figure also shows the three types of aquifers; (1) unconfined aquifer; (2) unconfined- semiconfined; and (3) semiconfined-confined aquifer. (b) Cross-section of the Cuballing catchment showing the various lithological units and the two different types of colluvium.

characterized by angular weathered granitic material; colluvium (B), present in the western areas of the catchment, is characterized by rounded lateritic particles. It is formed of clayey sand, with the clay content increasing downwards. On the western flank the regolith depth ranges from 20 to 30 m, while in the eastern areas it ranges from 2 to 10 m.

East Perenjori catchment

Logs from drilled wells in the East Perenjori catchment show the same succession of alluvium, colluvium (B) and weathered bedrock (Fig. 6a,b). In addition to a sandplain unit in the midslopes, a greyish clay layer is generally present beneath all sand units (Henschke 1989). Two shallow (< 1 m deep) hardpans, one silicified and the other ferruginous, occur below the valley flanks and floor (Fig. 6).

Wallatin Creek catchment

In the Wallatin Creek catchment the depth to bedrock is very irregular with bedrock highs and dykes forming ridges. Additional drilling by CSIRO has shown the existence of significant depths of valley sediment (ranging from 15 to 30 m), extensive deeply weathered and altered bedrock zones to 30 m deep on the flanks, and the widespread presence of a 5–10 m thick coarse gravelly basal aquifer formed mainly from subangular to subrounded weathered basement particles (Fig. 7). The same succession of colluvium (A) and (B), sandplain and alluvium also occurs in the catchment. The percentage of coarser material is usually high along the channels with coarser sediment (2–5 thick) at the base.

RELICT CHANNELS

The term relict channels is used here to describe prior streams and channels which have been filled with aeolian, colluvium or alluvial sediment. They usually occur along or within the existing streams which have been reactivated after clearing native vegetation. A comparative study of two sets of aerial photographs for the East Perenjori catchment, one set taken before clearing (1962) and a recent set (1988) taken after clearing, show that the existing surface drainage system was not present before clearing (Fig. 8a,b). Examination of the aerial photographs show that the recently developed stream was originally a depression covered by native vegetation. The aerial photograph shows that the vegetation along this line was well established compared with other parts of the catchment. More runoff was generated after clearing, and stream flow recommenced along the low lying drainage line. Drilling along this recently developed channel (wells 22 to 30) confirms the presence of alluvial sediments with well-rounded to subrounded grains to a depth of 28 m, which had been deposited by prior streams. The presence of a well-developed delta in the outlet of the stream supports this argument (Fig. 8c).

Although no aerial photographs were taken in the Wallatin Creek catchment before clearing, local farmers confirmed that the same phenomena occurred there. Before clearing, there were no defined creek lines, but after clearing drainage developed in topographic lows along which the relict channels were present. In Wallatin Creek, aerial photograph interpretation has also shown the widespread presence of relict channels over the catchment, particularly in the valley floors (Fig. 9). The surface expression of the relict channels are known locally by farmers as 'sand seams', because the channels have been filled in by aeolian, alluvial and colluvial sand. Core samples from wells drilled along the relict channels contain

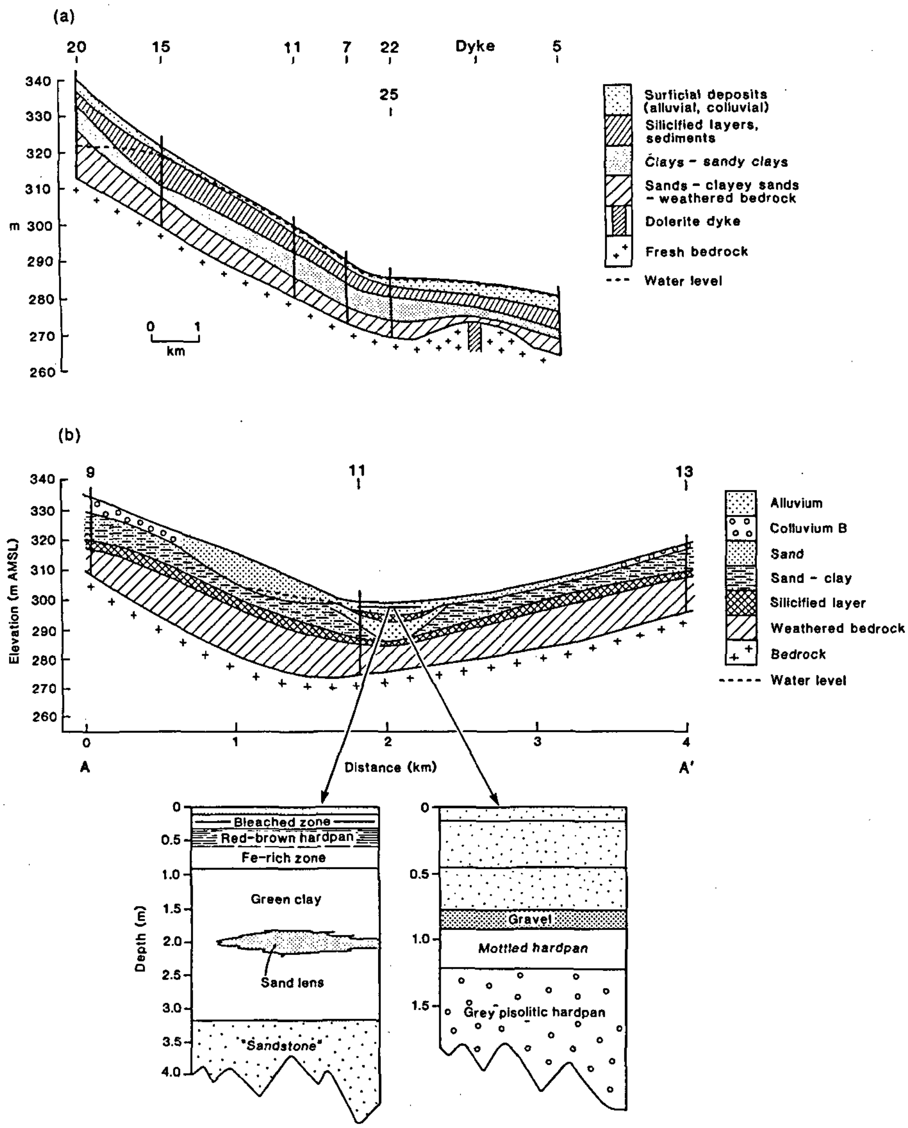

Fig. 6 (a) Cross-section of the East-Perenjori catchment, showing the extent of the silicified layer the basement high and associated dyke. The distribution of colluvium, sand plains, alluvium, hard pans and silicified layers are shown in detail in (b). (Section modified from Henschke 1989.)

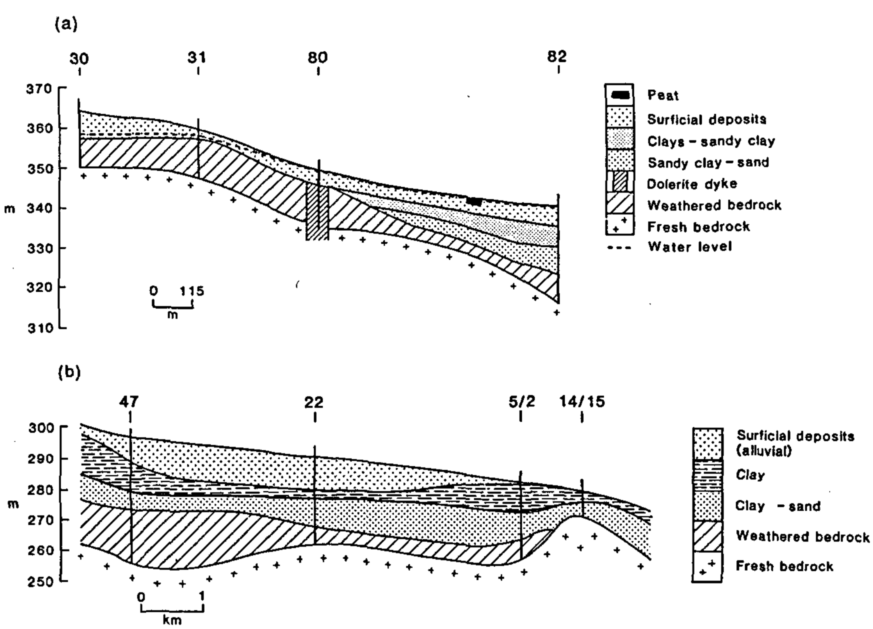

Fig. 7 Simplified cross-section at (a) Harvey section shows a weathering profile upstream of the dyke and a sedimentary profile downstream with peat beds. (b) Wallatin Creek Section shows the widespread clayey material and the basement high (A in Fig. 4).

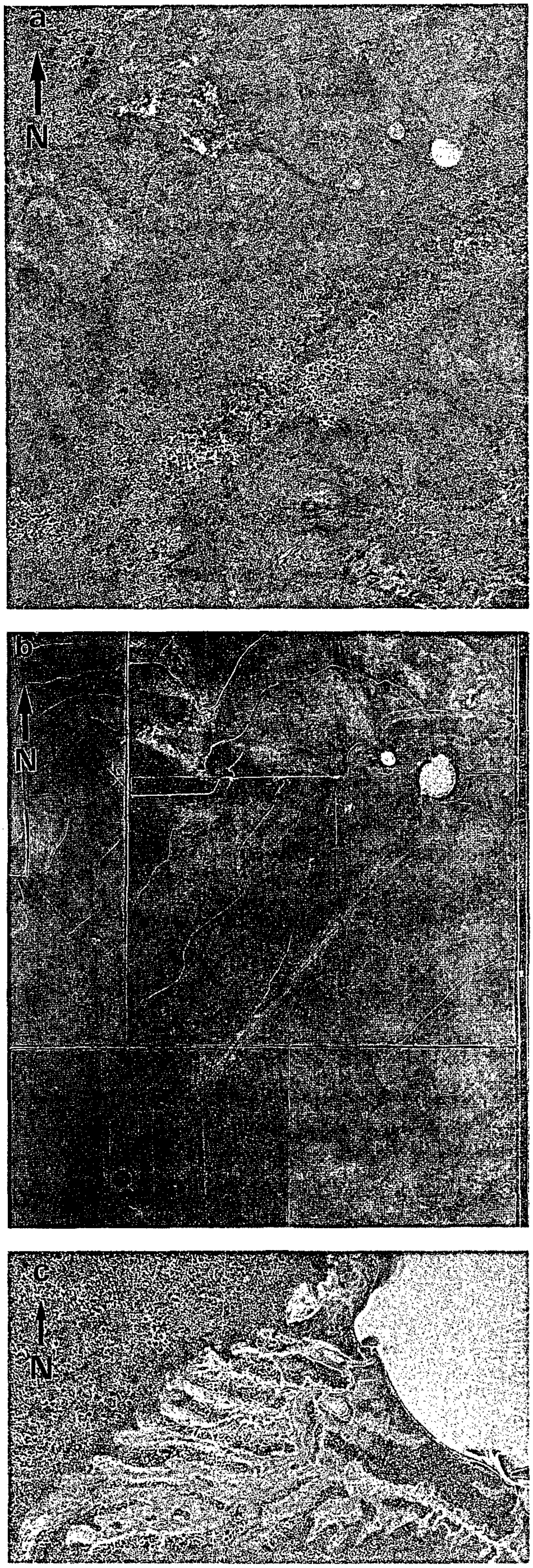

Fig. 9 Aerial photograph from Wallatin Creek catchment showing the relict channels in the downstream half of the catchment. (Reproduced by permission of the Department of Land Administration, Perth, Western Australia.)

rounded to subrounded sand particles in the downstream areas of the catchment as well as in the upstream areas. Peat beds crop out in two areas in the catchment. The first bed crops out in the stream floor and the banks of the creek at Wallatin Section (Fig. 4). The second site is in the banks of the stream near Harvey section. The peat located at Wallatin Creek Section is associated with black carbonaceous sediments and fragments of tree branches. Palynological techniques indicate that the peat is Pliocene to Miocene in age (Salama 1992). Small scattered pieces of peat and carbonaceous matter have been found in core samples from wells drilled near to the streams (i.e. 85, 106 and 116).

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Fig. 8 Aerial photographs from East Perenjori (a) before clearing and (b) after clearing; showing the development of the stream after clearing, the increase in lake size and the development of salinity. Part of the geological structure extending across the drainage line appears on the right hand corner. (c) Aerial photograph from East Perenjori showing the well developed delta in the downstream part of the catchment. (Reproduced by permission of the Department of Land Administration, Perth, Western Australia.)

HYDROGEOLOGY

Cuballing catchment

The catchment drains into a seasonally flowing tributary of the Hotham River which discharges into the Murray River. The outlet of the stream from the catchment is constricted by a granitic outcrop extending across the stream. The main stream follows a northward lineament along which the channel has developed (Fig. 2). Three groundwater systems have been recognized in the catchment. One is a shallow unconfined system, which is ephemeral on the eastern valley sides, and permanent in the valley floor. The second is a permanent shallow watertable to semiconfined aquifer usually present in the western flanks. The third system is a semiconfined to confined aquifer which occurs in the alluvial sediment within the channel and extends outwards in the weathered rock material. This division is based on the lithological patterns, the relative position of water levels in relation to the water bearing formation, the presence or absence of a confining layer, and the analysis of water level patterns of monitored boreholes (Salama *et al.* 1991).

East Perenjori catchment

In the East Perenjori catchment, surface water drains to the northeast into Mongers Lake through a main channel which originates in the upper part of the catchment to the south (Fig. 3). The channel follows along a northeast lineament which passes through a zone constricted by basement rock and along the central area of the catchment where the gradient is very subdued. The stream enters Mongers Lake through an incised channel in red loamy sand with layers of calcrete. The hard pan plays an important role in the shallow groundwater movement in the valley floor areas of the catchment. Where shallow sandy layers exist on top of the hardpan, a perched aquifer can be found. In the absence of the hardpan, a shallow unconfined aquifer exists on top of the clay layer. A second unconfined aquifer extends below the sandplains and over most of the alluvial channels and becomes semiconfined below clayey layers. A third semiconfined to confined aquifer extends over most of the catchment and is formed of highly weathered material at the catchment divide and fluvial sediment in the valleys.

Wallatin Creek catchment

A detailed study of the drainage pattern in the Wallatin Creek catchment shows that in the northern half of the catchment the main stream follows a north to northwest direction, whereas the tributaries of the main stream follows a northeast direction (Fig. 10). The tributaries in the southern half of the catchment follow an east–west direction. This indicates that drainage in Wallatin Creek follows the pattern of major lineaments in the Yilgarn Craton.

Logs of wells drilled in the catchment show that, as with the other catchments, there are three aquifer systems.

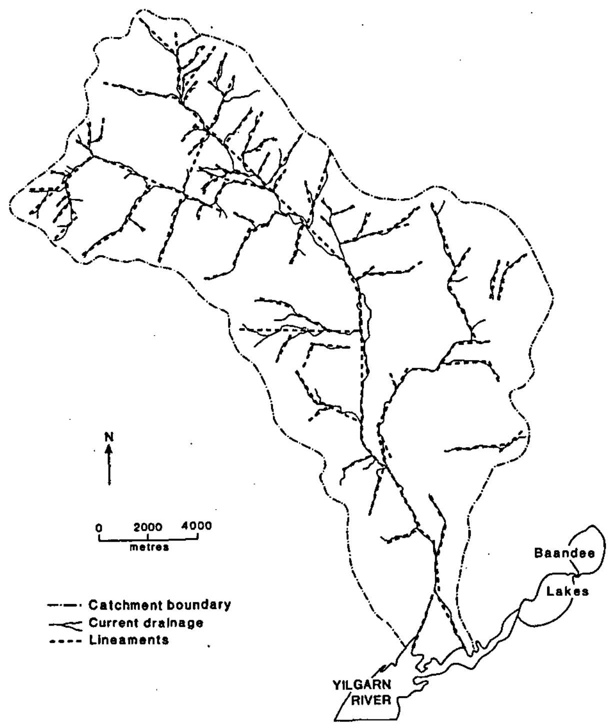

Fig. 10 Wallatin Creek catchment, showing the systematic pattern of the current drainage system. The drainage is following the pattern of major lineaments in the Yilgarn Craton.

The first is an unconfined aquifer which is present above a clay layer in the sandplain and valleys, and the second is a semiconfined aquifer below this clay layer. The third aquifer is a deeper, semiconfined to confined, regional aquifer which occurs in the weathered zone above the bedrock and extends into the sediment of the relict channels in the valleys and the flanking areas.

GROUNDWATER SALINITY

Cuballing catchment

The plot of Cl against total dissolved ions for groundwater samples from Cuballing catchment shows a linear relationship which can be classified into three distinct groups based on the aquifer type (Fig. 11a). Groundwater in the shallow unconfined aquifer (group A) is generally low in chloride (20–770 mg/L) since this aquifer is usually well drained. There are some exceptions where wells have higher salinity. These include well 3A which is upstream from the major constriction across the drainage line. The restriction in groundwater flow causes a rise in water level and increase in salinity (Fig. 11b). Groundwater salinity in the confined aquifer (group C) is usually less than 4000 mg/L, except when the wells are upstream of geological structures (wells 3C and 5C). The highest salinity levels are encountered in the semiconfined aquifer (group B; 5100–5700 mg/L). The same straight line relationship between Cl and total dissolved ions is found in East Perenjori and Wallatin Creek catchments (Figs 12a, 13a).

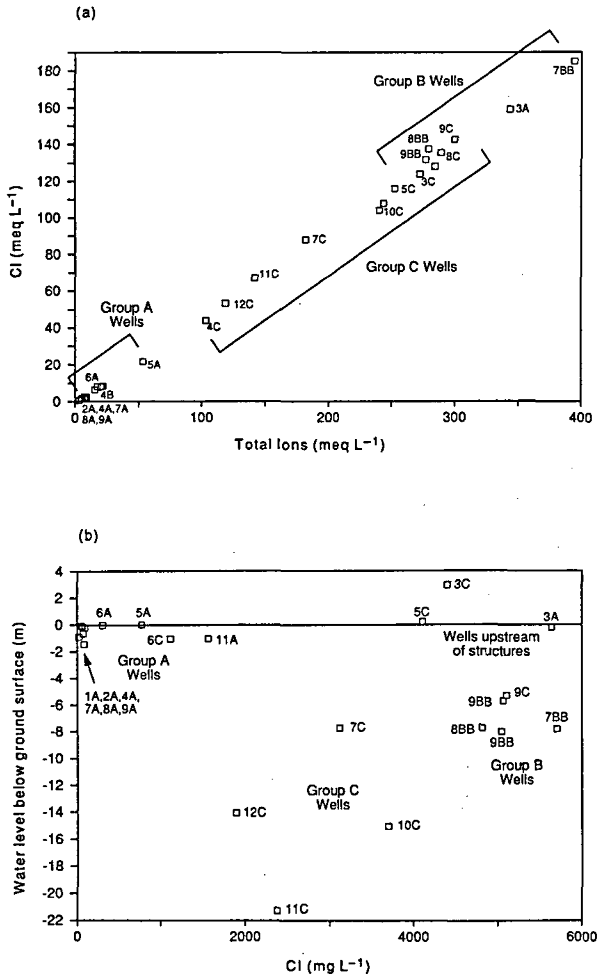

Fig. 11 (a) Concentration of chloride plotted against total ions for groundwater in Cuballing catchment, showing the straight line relationship and the three distinct well groups, Group A wells having the lowest salinity, followed by group C and B respectively. (b) Concentration of chloride plotted against water level, showing the effect of structures in raising the water level and salinity in Cuballing catchment. It also shows the well leached group A wells and the comparatively low salinity of group C wells compared with group B.

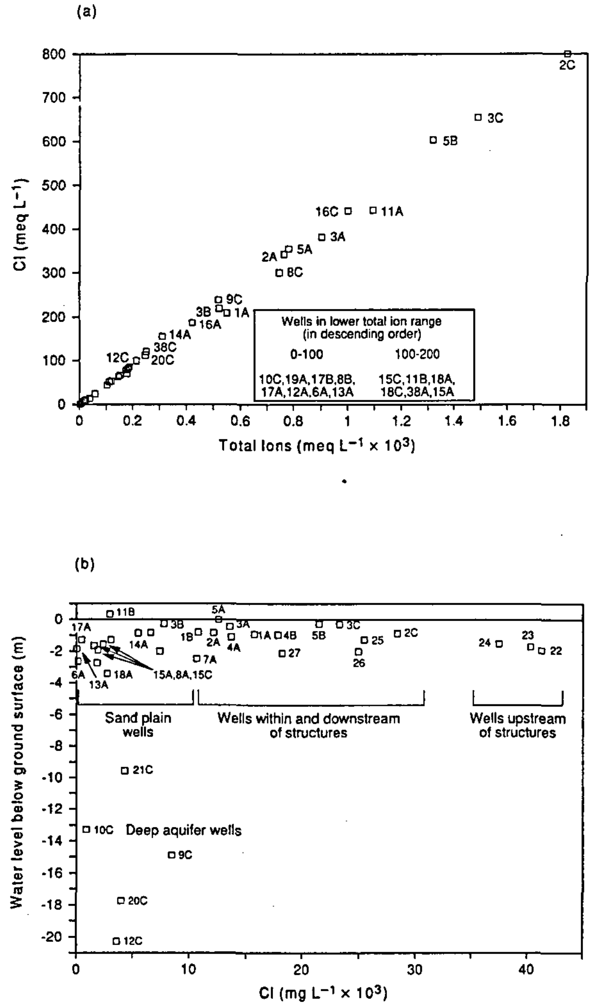

Fig. 12 (a) Concentration of chloride plotted against total ions for groundwater in East Perenjori catchment. (b) Concentration of chloride plotted against water levels in East Perenjori catchment showing the high salinity of wells upstream of geological structures, and the high salinity of groundwater from wells within and downstream of the major structure. It also shows the low salinity of wells in the sand plain aquifer and in the deep aquifer in the water shed areas.

East Perenjori catchment

In East Perenjori, low salinity levels occur in groundwaters from aquifers in the sandplain slopes and in weathered material above bedrock in the upper area of the catchment (Fig. 12b). Groundwater from wells upstream from a basement high extending across the drainage line in the central part of the section have the highest salinity levels in the catchment, for example, well 22 (41 000 mg/L) and well 23 (40 000 mg/L). These wells are outside the range used for Fig. 12a but plot in a separate group in Fig. 12b. In the lower area of the catchment the presence of dykes and basement highs also restrict groundwater flow and causes elevated salinity levels in all aquifers (e.g. wells 1, 2, 3, 26 and 27).

Wallatin Creek catchment

Salinity in the Wallatin Creek catchment follows similar trends to the other two catchments. Low salinity levels occur in groundwater from wells in the sandplain and the shallow aquifers over basement rock. For example, in wells 43, 44, 45, 46 and 47 (A in Fig. 13a), which were drilled in a typical sand plain area, salinity is lowest at the top of the catchment (1300 mg/L at well 43) but increases progressively in the aquifer farther downstream along the flowpath. Salinity along the relict channels also follows a systematic increase downstream, with higher salinity values occurring in the uncleared catchments compared with the cleared ones. In the Durokoppin Nature Reserve subcatchment, which is uncleared, salinity

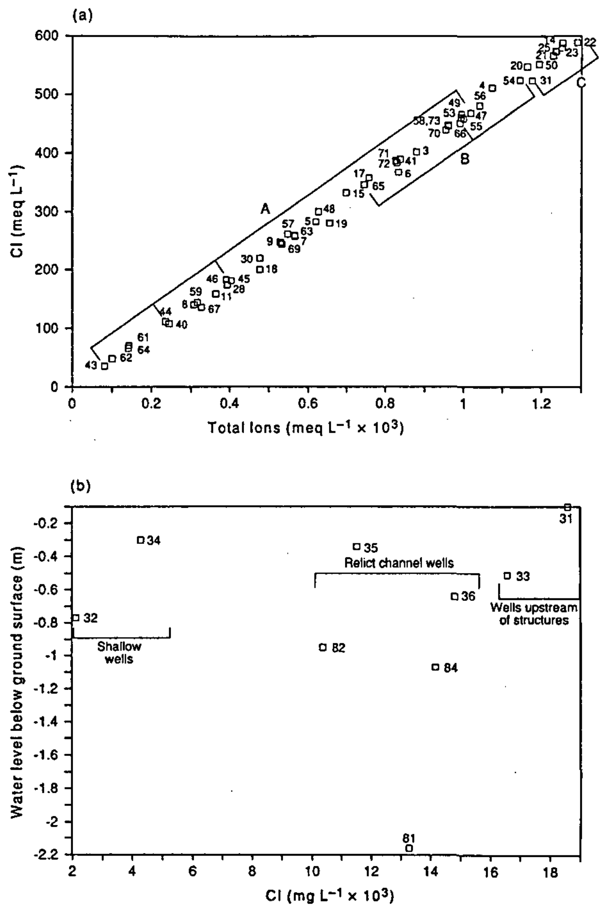

Fig. 13 (a) Concentration of chloride plotted against total ions for groundwater in Wallatin Creek catchment showing the increase of salinity along the flow path in a recent channel (A) and along a relict channel (B). The highest salinity is recorded from wells upstream of geological structures and in relict channels (C). (b) Concentration of chloride plotted against water levels showing the high salinity of wells upstream of geological structures in Harvey catchment.

in groundwater from wells along the relict channels was 12 300 mg/L (well 65) in the upstream area and increased progressively downstream to a high value of 16 600 mg/L at well 66 and 18 600 mg/L at well 54 along the flow path (B in Fig. 13a). In the southern part of the reserve, wells away from the channel have low Cl values of 1700 mg/L (well 62), whereas wells in the relict channels have higher salinities (9200 mg/L; well 63). In the Harvey subcatchment, which is cleared, salinities range from 7800 mg/L in wells near the catchment divide (well 30) to 16 500–18 600 mg/L in wells in the depression (wells 31 and 33; Fig. 13b). The large increase is caused by the damming effect of a dyke detected in aerial photographs and confirmed by drilling (Fig. 7b). The salinity in wells drilled along the relict channel varies from 11 500 mg/L (well 35) to 15 000 mg/L (well 84). Very high salinity levels are found in groundwater from wells upstream of basement highs (50 000 mg/L at well 10 and 21 000 mg/L at well 50; C in Fig. 13a).

DISCUSSION AND CONCLUSIONS

Geological structures

In the southwestern province of the Yilgarn block, the regional tectonic trend is mainly northwest with the northerly trend becoming more prominent along the western margin of the province parallel to the Darling Fault (Williams 1975). Dolerite dykes and basement highs have been mapped in all three catchments and were found to divide the catchments into a series of hydrologic compartments. In the Wallatin Creek catchment, groundwater flow in the drainage line is impeded by a series of dykes and basement highs which extend across the drainage system in the central part of the catchment. The surface drainage lines in the catchments often follow the northeast or northwest trends in the basement along the existing and relict river systems. In East Perenjori the catchment is divided into two compartments: the southern one, upstream of the basement high and associated dykes, is relatively fresh and the water is used for stock; and the area directly upstream of the structures and all the area downstream have very high salinity levels. The same pattern applies to the Cuballing catchment.

Relict channels

The study also shows the presence of an intricate system of relict channels which extend over most of the catchments, with well developed deltaic systems at the outlet of the Wallatin Creek and East Perenjori catchments. The relict channels occupy the same valley as the present streams. The relict channels are characterized by the presence of well developed sedimentary sequences which have a thickness of about 10–30 m in all three catchments. These observations suggest that the sedimentary deposits are not only more widespread than previously thought, but also the area has been subject to alternating periods of erosion, deposition, fluviation and sedimentation.

Chemical model

Most of the variation in salinity of the groundwater in the aquifers of the three study catchments can be explained by the distribution of the geological structures and relict channels. Salinities in the relict channels are generally higher than in other areas of the catchment. Salinity also increases in the direction of groundwater flow along the relict channels from the top of the catchment divide to the valleys. Salinity in groundwaters upstream from geological structures (dykes, veins and basement highs) is without exception higher than in the other parts of the catchment. The highest groundwater salinity recorded in the Wallatin Creek catchment is in wells upstream of basement highs and dykes (wells 10, 14, 101–104; Figs 4, 13b). Similarly in the East Perenjori and Cuballing catchments, salinity is highest in groundwater from wells in the central part of the catchments which are upstream from a series of dykes running across the drainage line (Figs 12a,b). In some cases, as in the Cuballing catchment, the deeper aquifer (3) is lower in salinity than the second aquifer (2). This can be explained by two main factors. The first factor is that the salt distribution down the regolith usually takes the form of a bulge profile (Johnston *et al.* 1980) and the second aquifer system usually is within this zone. The second factor is that the third aquifer receives more recharge through the fractures and joints of rock outcropping areas in the water shed parts of the catchment (Salama *et al.* 1991). All the chemical data from the three catchments have a straight line relationship for Cl and total dissolved ions. This suggests that increase in salinity is due to loss of water either through evaporation or uptake of water by plant roots or through the weathering process (Salama *et al.* 1992).

The spatial distribution of groundwater salinities shows that dykes and basement highs impose a barrier to groundwater flow along the relict channels and cause the groundwater upstream from the barrier to increase in height and salinity. If the barriers are close to the soil surface severe salinization occurs.

Aerial photograph interpretation

Aerial photogeological interpretation techniques have been used successfully to map the geology, delineate the geological structures and identify the relict channels in the three catchments. When compared with the results from previous geophysical studies in the catchments at Cuballing (Engel *et al.* 1987) and East Perenjori (Henschke 1989), all of the dykes and basement highs mapped by the geophysical methods have been detected from aerial photographs and were identified on the ground. For widespread management of the salinity in the wheatbelt of Western Australia, aerial photogeological interpretation with field validation is a very effective, simple, fast and inexpensive technique for mapping salinity related structures. This technique offers an ideal opportunity for farmers in land care groups, farm managers and land management officers to assess potential salinity problems.

ACKNOWLEDGEMENTS

The authors thank the following officers of the Western Australian Department of Agriculture: Dr Bob Nulsen, Dr Richard George and Mr Chris Henschke (now of South Australian Department of Agriculture) for their generous support in making available the instrumented catchments and earlier results. The authors also thank the farmers in the three catchments for their generosity in making land and facilities available, and Mrs Jan Hosking of CSIRO Division of Water Resources for chemical analyses of groundwater samples. Financial support by the National Soil Conservation Programme is acknowledged. The constructive comments of Mr David Williamson, Mr Max Churchward, Dr Richard George, Dr Phil Commander and Dr Chris Barber were appreciated. Aerial photographs are reproduced by permission of the Department of Land Administration, Perth, Western Australia, under Copy Licence 306/92.

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(*Received* 15 *January* 1991; *accepted* 12 *December* 1991)